Free Executive Summary

Surface Temperature Reconstructions for the Last 2,000 Years

Committee on Surface Temperature Reconstructions for the Last 2,000 Years, National Research Council

ISBN: 0-309-10225-1, 196 pages, 7 x 10, paperback (2006)

Summary

Because widespread, reliable instrumental records are available only for the last 150 years or so, scientists estimate climatic conditions in the more distant past by analyzing *proxy evidence* from sources such as tree rings, corals, ocean and lake sediments, cave deposits, ice cores, boreholes, glaciers, and documentary evidence. For example, records of Alpine glacier length, some of which are derived from paintings and other documentary sources, have been used to *reconstruct* the time series of surface temperature variations in south-central Europe for the last several centuries. Studying past climates can help us put the 20th century warming into a broader context, better understand the climate system, and improve projections of future climate.

Starting in the late 1990s, scientists began combining proxy evidence from many different locations in an effort to estimate surface temperature changes averaged over broad geographic regions during the last few hundred to few thousand years. These *large-scale surface temperature reconstructions* have enabled researchers to estimate past temperature variations over the Northern Hemisphere or even the entire globe, often with time resolution as fine as decades or even individual years. This research, and especially the first of these reconstructions published in 1998 and 1999 by Michael Mann, Raymond Bradley, and Malcolm Hughes, attracted considerable attention because the authors concluded that the Northern Hemisphere was warmer during the late 20th century than at any other time during the past millennium. Controversy arose because many people interpreted this result as definitive evidence of anthropogenic causes of recent climate change, while others criticized the methodologies and data that were used.

In response to a request from Congress, this committee was assembled by the National Research Council to describe and assess the state of scientific efforts to reconstruct surface temperature records for the Earth over approximately the last 2,000 years and the implications of these efforts for our understanding of global climate change.

Figure S-1 shows a compilation of large-scale surface temperature reconstructions from different research groups, each using its own methodology and selection of proxies, as well as the instrumental record (beginning in 1856) of global mean surface temperature.

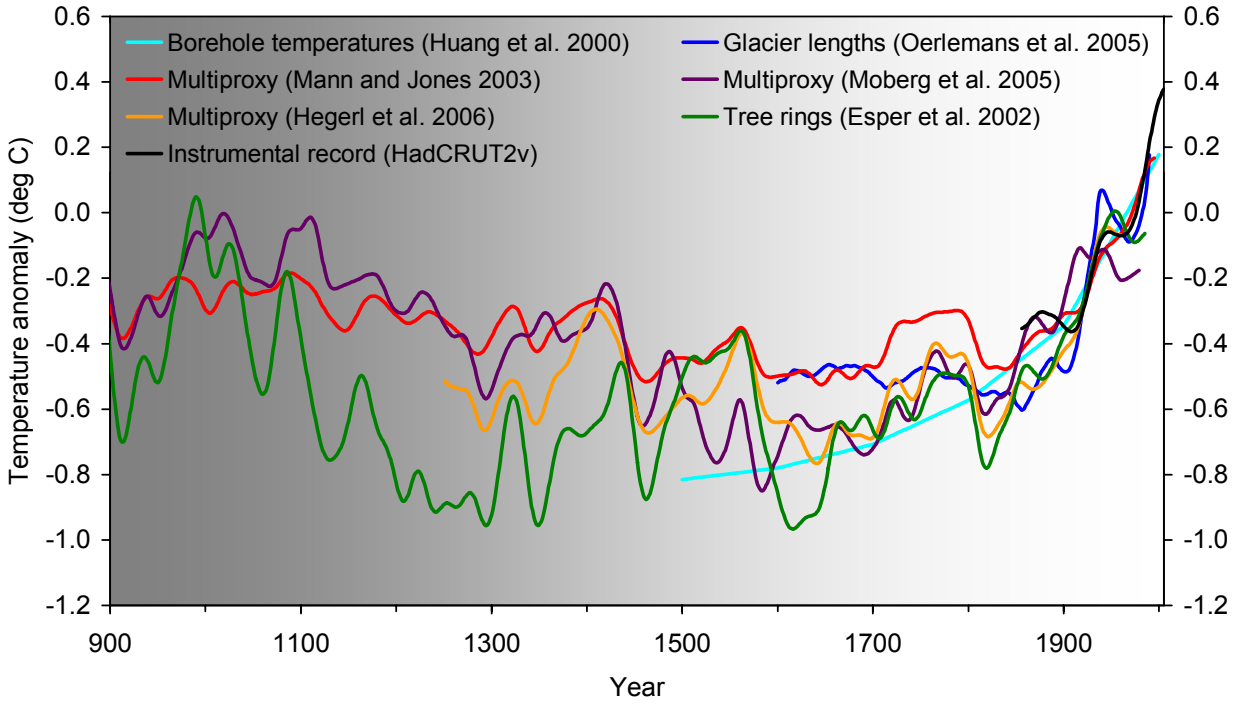

FIGURE S-1 Smoothed reconstructions of large-scale (Northern Hemisphere mean or global mean) surface temperature variations from six different research teams are shown along with the instrumental record of global mean surface temperature. Each curve portrays a somewhat different history of temperature variations, and is subject to a somewhat different set of uncertainties that generally increase going backward in time (as indicated by the gray shading). This set of reconstructions conveys a qualitatively consistent picture of temperature changes over the last 1,100 years, and especially the last 400. See Figure O-5 for details about each curve.

After considering all of the available evidence, including the curves shown in Figure S-1, the committee has reached the following conclusions:

- The instrumentally measured warming of about 0.6°C during the 20th century is also reflected in borehole temperature measurements, the retreat of glaciers, and other observational evidence, and can be simulated with climate models.
- Large-scale surface temperature reconstructions yield a generally consistent picture of temperature trends during the preceding millennium, including relatively warm conditions centered around A.D. 1000 (identified by some as the "Medieval Warm Period") and a relatively cold period (or "Little Ice Age") centered around 1700. The existence and extent of a Little Ice Age from roughly 1500 to 1850 is supported by a wide variety of evidence including ice cores, tree rings, borehole temperatures, glacier length records, and historical documents. Evidence for regional warmth during medieval times can be found in a diverse but more limited set of records including ice cores, tree rings, marine sediments, and historical sources from Europe and Asia, but the exact timing and duration of warm periods may have varied from region to region, and the magnitude and geographic extent of the warmth are uncertain.

- It can be said with a high level of confidence that global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period during the preceding four centuries. This statement is justified by the consistency of the evidence from a wide variety of geographically diverse proxies.
- Less confidence can be placed in large-scale surface temperature reconstructions for the period from A.D. 900 to 1600. Presently available proxy evidence indicates that temperatures at many, but not all, individual locations were higher during the past 25 years than during any period of comparable length since A.D. 900. The uncertainties associated with reconstructing hemispheric mean or global mean temperatures from these data increase substantially backward in time through this period and are not yet fully quantified.
- Very little confidence can be assigned to statements concerning the hemispheric mean or global mean surface temperature prior to about A.D. 900 because of sparse data coverage and because the uncertainties associated with proxy data and the methods used to analyze and combine them are larger than during more recent time periods.

The main reason that our confidence in large-scale surface temperature reconstructions is lower before A.D. 1600 and especially before A.D. 900 is the relative scarcity of precisely dated proxy evidence. Other factors limiting our confidence in surface temperature reconstructions include the relatively short length of the instrumental record (which is used to calibrate and validate the reconstructions); the fact that all proxies are influenced by a variety of climate variables; the possibility that the relationship between proxy data and local surface temperatures may have varied over time; the lack of agreement as to which methods are most appropriate for calibrating and validating large-scale reconstructions and for selecting the proxy data to include; and the difficulties associated with constructing a global or hemispheric mean temperature estimate using data from a limited number of sites and with varying chronological precision. All of these considerations introduce uncertainties that are difficult to quantify.

Despite these limitations, the committee finds that efforts to reconstruct temperature histories for broad geographic regions using multiproxy methods are an important contribution to climate research and that these large-scale surface temperature reconstructions contain meaningful climatic signals. The individual proxy series used to create these reconstructions generally exhibit strong correlations with local environmental conditions, and in most cases there is a physical, chemical, or physiological reason why the proxy reflects local temperature variations. Our confidence in the results of these reconstructions becomes stronger when multiple independent lines of evidence point to the same general result, as in the case of the Little Ice Age cooling and the 20th century warming.

The basic conclusion of Mann et al. (1998, 1999) was that the late 20th century warmth in the Northern Hemisphere was unprecedented during at least the last 1,000 years. This conclusion has subsequently been supported by an array of evidence that includes both additional large-scale surface temperature reconstructions and pronounced changes in a variety of local proxy indicators, such as melting on icecaps and the retreat of glaciers around the world, which in many cases appear to be unprecedented during at least the last 2,000 years. Not all individual proxy records indicate that the recent warmth is unprecedented, although a larger fraction of geographically diverse sites experienced exceptional warmth during the late 20th century than during any other extended period from A.D. 900 onward.

Based on the analyses presented in the original papers by Mann et al. and this newer supporting evidence, the committee finds it plausible that the Northern Hemisphere was warmer

during the last few decades of the 20th century than during any comparable period over the preceding millennium. The substantial uncertainties currently present in the quantitative assessment of large-scale surface temperature changes prior to about A.D. 1600 lower our confidence in this conclusion compared to the high level of confidence we place in the Little Ice Age cooling and 20th century warming. Even less confidence can be placed in the original conclusions by Mann et al. (1999) that "the 1990s are likely the warmest decade, and 1998 the warmest year, in at least a millennium" because the uncertainties inherent in temperature reconstructions for individual years and decades are larger than those for longer time periods, and because not all of the available proxies record temperature information on such short timescales.

Surface temperature reconstructions for periods prior to the industrial era are only one of multiple lines of evidence supporting the conclusion that climatic warming is occurring in response to human activities, and they are not the primary evidence.

Surface temperature reconstructions also provide a useful source of information about the variability and sensitivity of the climate system. To within existing uncertainties, climate model simulations show that the estimated temperature variations during the two millennia prior to the Industrial Revolution can be explained plausibly by estimated variations in solar radiation and volcanic activity during the same period.

Large-scale surface temperature reconstructions have the potential to further improve our knowledge of temperature variations over the last 2,000 years, particularly if additional proxy evidence can be identified and obtained from areas where the coverage is relatively sparse and for time periods before A.D. 1600 and especially before A.D. 900. Furthermore, it would be helpful to update proxy records that were collected decades ago, in order to develop more reliable calibrations with the instrumental record. Improving access to data used in publications would also increase confidence in the results of large-scale surface temperature reconstructions both inside and outside the scientific community. New analytical methods, or more careful use of existing ones, may also help circumvent some of the existing limitations associated with surface temperature reconstructions based on multiple proxies. Finally, because some of the most important potential consequences of climate change are linked to changes in regional circulation patterns, hurricane activity, and the frequency and intensity of droughts and floods, regional and large-scale reconstructions of changes in other climatic variables, such as precipitation, over the last 2,000 years would provide a valuable complement to those made for temperature.

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Committee on Surface Temperature Reconstructions for the Last 2,000 Years
Board on Atmospheric Sciences and Climate
Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

International Standard Book Number X-XXX-XXXXX-X (Book)

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Printed in the United States of America.

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Foreword

Our understanding of climate and how it has varied over time are advancing rapidly as new data are acquired and new investigative instruments and methods are employed. Thus in 2005, I suggested to the U. S. Congress that the National Research Council (NRC) could help to answer questions about the data and methods that have been used in constructing records of Earth's surface temperatures from times when there were no scientific instruments, using proxy indicators. How has temperature varied over the last 2,000 years? How certain is the answer to this question?

Subsequently, this study was requested by Representative Sherwood Boehlert, Chairman of the Committee on Science, U.S. House of Representatives. Chairman Boehlert asked for a clear and concise report in a relatively short period of time, and the NRC agreed to undertake the study quickly. An *ad hoc* committee was formed, with the group carefully composed to include the breadth and depth of expertise and perspectives needed to analyze all aspects of how surface temperatures are estimated and interpreted, and to comment generally on climate science. The NRC asked the committee to summarize current scientific information on the temperature record for the past two millennia, describe the main areas of uncertainty and how significant they are, describe the principal methodologies used and any problems with these approaches, and explain how central is the debate over the paleoclimate temperature record to the state of scientific knowledge on global climate change.

The committee has prepared a report that, in my view, provides policy makers and the scientific community with a critical view of surface temperature reconstructions and how they are evolving over time, as well as a good sense of how important our understanding of the paleoclimate temperature record is within the overall state of scientific knowledge on global climate change. The report does not make policy recommendations.

I thank the members of the committee, who worked intensely to produce this careful report in a short period of time and contributed much personal time, insight, and energy. The NRC staff, and all those who contributed papers, data, graphics, and other information, as well as the independent experts who participated in the rigorous review process, were essential participants.

Ralph J. Cicerone, President
National Academy of Sciences
Chair, National Research Council

Preface

This committee was asked to describe and assess the state of scientific efforts to reconstruct surface temperature records for the Earth over approximately the last 2,000 years. (The full Statement of Task appears in Appendix A.) Normally, a technical issue such as surface temperature reconstructions might not generate widespread attention, but this case brings interesting lessons about how science works and how science, especially climate science, is communicated to policy makers and the public. The debate began in 1998 when a paper by Michael Mann, Raymond Bradley and Malcolm Hughes was published in the journal Nature. The authors used a new methodology to combine data from a number of sources to estimate temperatures in the Northern Hemisphere for the last six centuries, and later for the last 1,000 years. This research received wide attention, in part because it was illustrated with a simple graphic, the so-called hockey stick curve, that many interpreted as definitive evidence of anthropogenic causes of recent climate change. The research was given prominence in the 2001 report of the Intergovernmental Panel on Climate Change, and then picked up by many in the wider science community and by the popular media.

Science is a process of exploration of ideas—hypotheses are proposed and research is conducted to investigate. Other scientists work on the issue, producing supporting or negating evidence, and each hypothesis either survives for another round, evolves into other ideas, or is proven false and rejected. In the case of the hockey stick, the scientific process has proceeded for the last few years with many researchers testing and debating the results. Critics of the original papers have argued that the statistical methods were flawed, that the choice of data was biased, and that the data and procedures used were not shared so others could verify the work. This report is an opportunity to examine the strengths and limitations of surface temperature reconstructions and the role that they play in improving our understanding of climate. The reconstruction produced by Dr. Mann and his colleagues was just one step in a long process of research, and it is not (as sometimes presented) a clinching argument for anthropogenic global warming, but rather one of many independent lines of research on global climate change.

Using multiple types of proxy data to infer temperature time series over large geographic regions is a relatively new area of scientific research, although it builds upon the considerable progress that has been made in deducing past temperature variations at single sites and local regions. Surface temperature reconstructions often combine data from a number of specialized disciplines, and few individuals have expertise in all aspects of the work. The procedures for dealing with these data are evolving—there is no one "right" way to proceed. It is my opinion that this field is progressing in a healthy manner. As in all scientific endeavors, research reported in the scientific literature is often "work in progress" aimed at other investigators, not always to be taken as individual calls for action in the policy community.

With this as context, the committee considered the voluminous literature pertinent to its charge and received briefings and written contributions from more than two dozen people. We have organized our report knowing that we have at least two different audiences—the science community and the policy community. The principal conclusions of the committee are listed in the Summary and explained in the Overview using nontechnical language. More extensive

technical justifications for the committee's conclusions, including references, are presented in the chapters that follow.

Finally, let me thank the members of the Committee on Surface Temperature Reconstructions for the Last 2,000 Years. The committee worked tirelessly over the last few months to assess the status of this field of research so that the public can see exactly what is involved, what we currently know about it, and what the prospects are for improving our understanding. We have tried to make clear how this piece of the climate puzzle fits into the broader discussions about global climate change.

Gerald R. North, *Chair*
Committee on Surface Temperature Reconstructions for the Last 2,000 Years

Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Peter Huybers, Woods Hole Oceanographic Institution
Carl Wunsch, Massachusetts Institute of Technology
Connie Woodhouse, National Oceanic and Atmospheric Administration
Julia Cole, University of Arizona
Lonnie Thompson, The Ohio State University
David Chapman, University of Utah
Ricardo Garcia-Herrera, Universidad Complutense de Madrid
David Brillinger, University of California, Berkeley
Robert Stine, University of Pennsylvania
Alexander Flax, Independent consultant
Claus Frohlich, PMOD Technologies
Richard Muller, Lawrence Berkeley Laboratory
Thomas Crowley, Duke University

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Andrew R. Solow, Woods Hole Oceanographic Institution, and Louis J. Lanzerotti, New Jersey Institute of Technology. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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